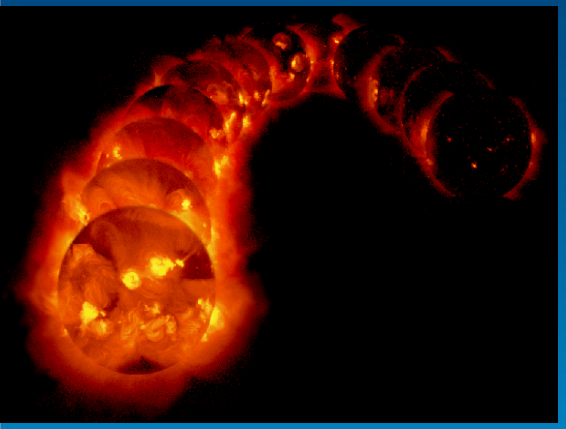
SHIELDS/RAM-SCB and Opportunities for Partnership with CCMC

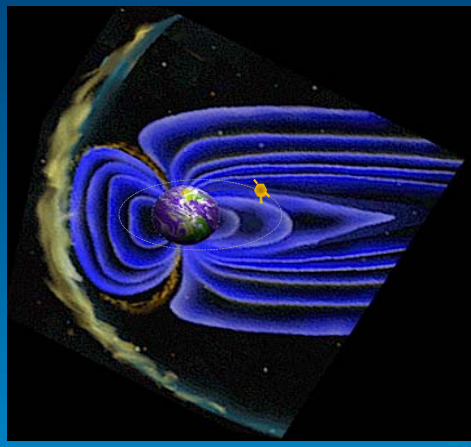
Vania Jordanova & the SHIELDS Team



Project Goals & Scientific Impact:

- **Develop a new space weather capability to understand, model, and predict:**

  Space Hazards Induced near Earth by Large, Dynamic Storms (SHIELDS)

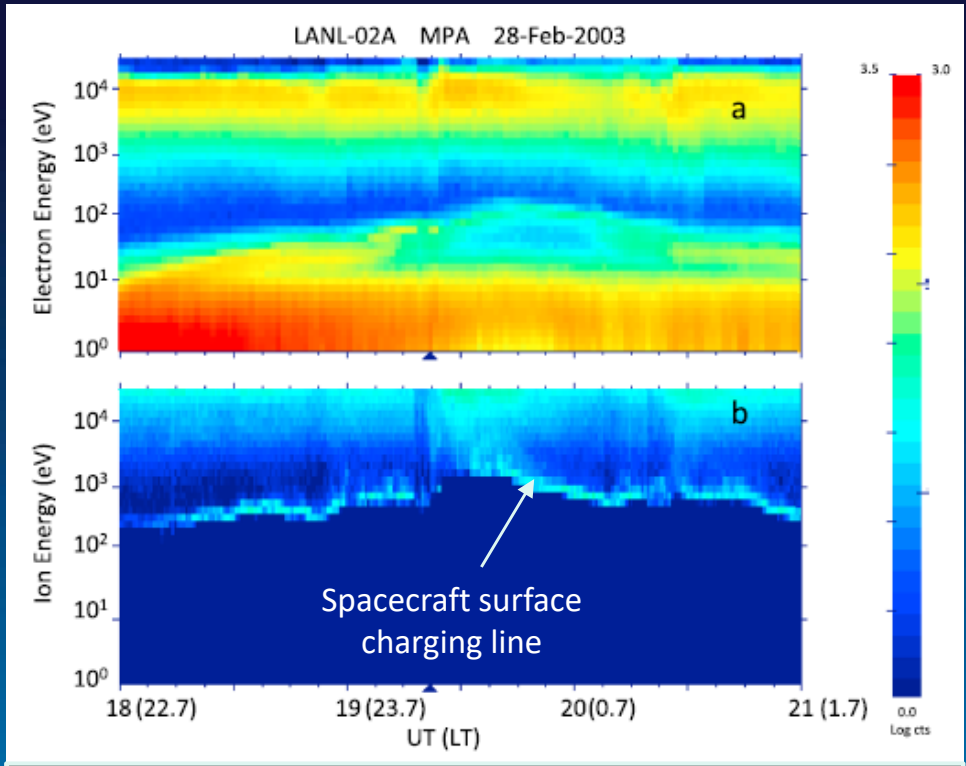


9th CCMC Workshop, College Park, MD

23-27 April 2018

Satellite Anomalies

- Some spacecraft are equipped with sensors to:
  - Monitor charged particles in the radiation belts
  - Help determine the cause and conditions under which spacecraft anomalies occur
- Most spacecraft are not equipped with space weather instruments
- LANL MPA data reveals the electron energy range (~5–10 keV) are most closely associated with satellite surface charging



Measurements from the Magnetospheric Plasma Analyzer (MPA) aboard the geosynchronous LANL-02A satellite on Feb 28th, 2003. Spacecraft surface charging is seen in both the electrons (top) and ions (bottom). [Thomsen et al., 2013]

The accurate global specification of the surface charging environment (SCE) fluxes of hot (~10's keV) electrons is the gap that SHIELDS fills!

SHIELDS Team

Funded by the U. S. Department of Energy through the Los Alamos National Laboratory (LANL) Laboratory Directed Research and Development (LDRD) program, the SHIELDS framework is being developed by world-class experts in the fields of space sciences and computational plasma physics:

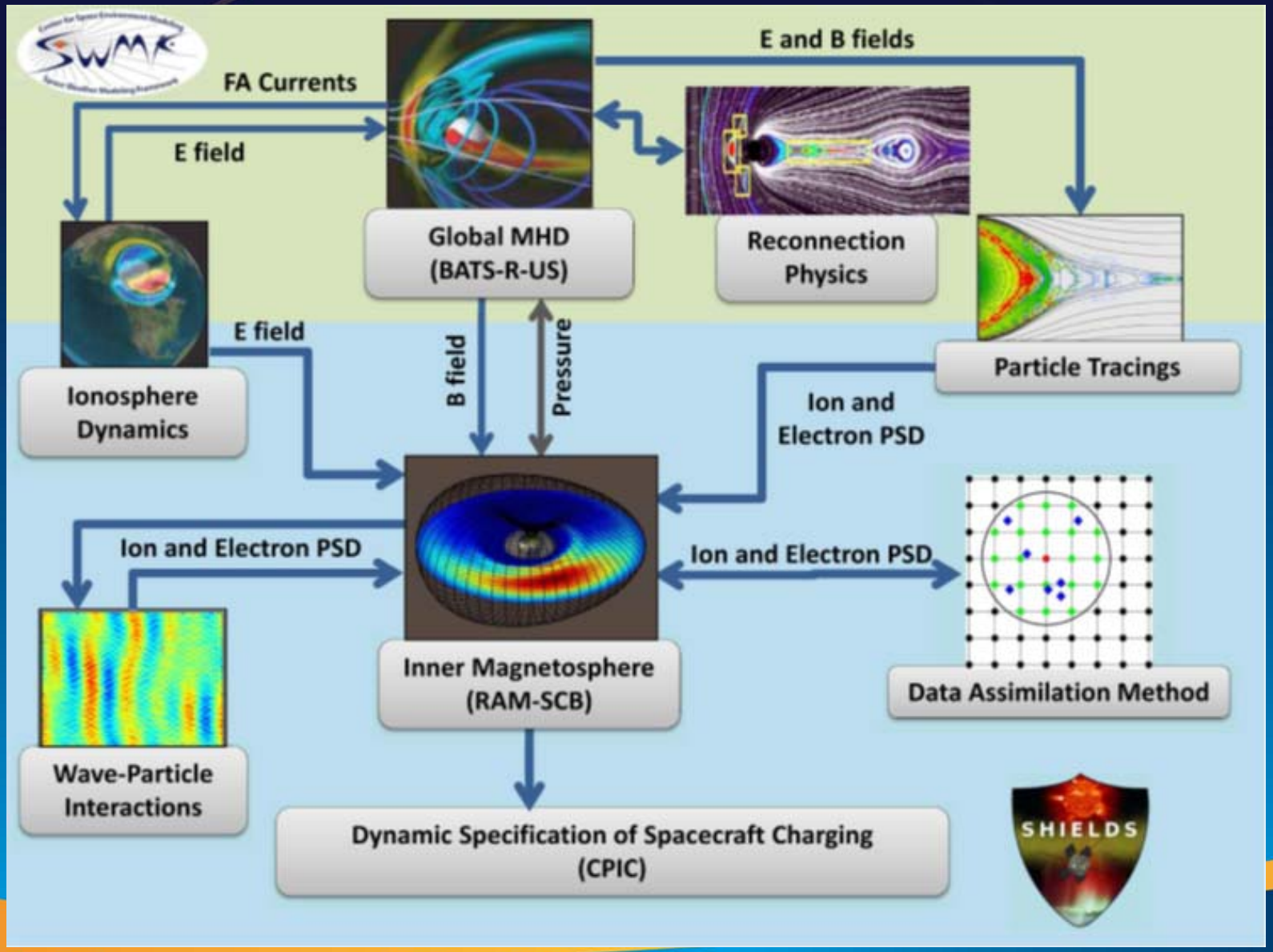
- V. Jordanova (PI), M. Henderson, C. Jeffery, S. Morley, D. A. Panaitescu, J. Woodroffe, T. Brito, M. Engel, ISR, LANL
- G. L. Delzanno (Co-PI), J. D. Moulton, H. Godinez, C. Meierbachtol, D. Svyatsky, T, LANL
- E. Lawrence, L. Vernon, CCS, LANL
- G. Tóth (Co-PI), D. Welling, Y. Chen, J. Haiducek, University of Michigan

Collaborators:

- M. Thomsen (PSI) and J. Birn, J. Borovsky and M. Denton, SSI
- J. Albert and S. Young, AFRL, Albuquerque, NM
- R. Horne, BAS, Cambridge, UK
- C. Lemon, The Aerospace Corporation, CA
- S. Markidis, I. B. Peng, KTH Stockholm, Sweden
- Y. Yu, Beihang University, Beijing, China

The SHIELDS Framework

Bridging macro- and micro-scale models, combined with data assimilation tools:
- **Capture rapid particle injection and acceleration during storms/substorms**
- **Include plasma wave generation and their feedback on the particles**



LDRD innovation for our nation

2017 R&D 100 WINNER

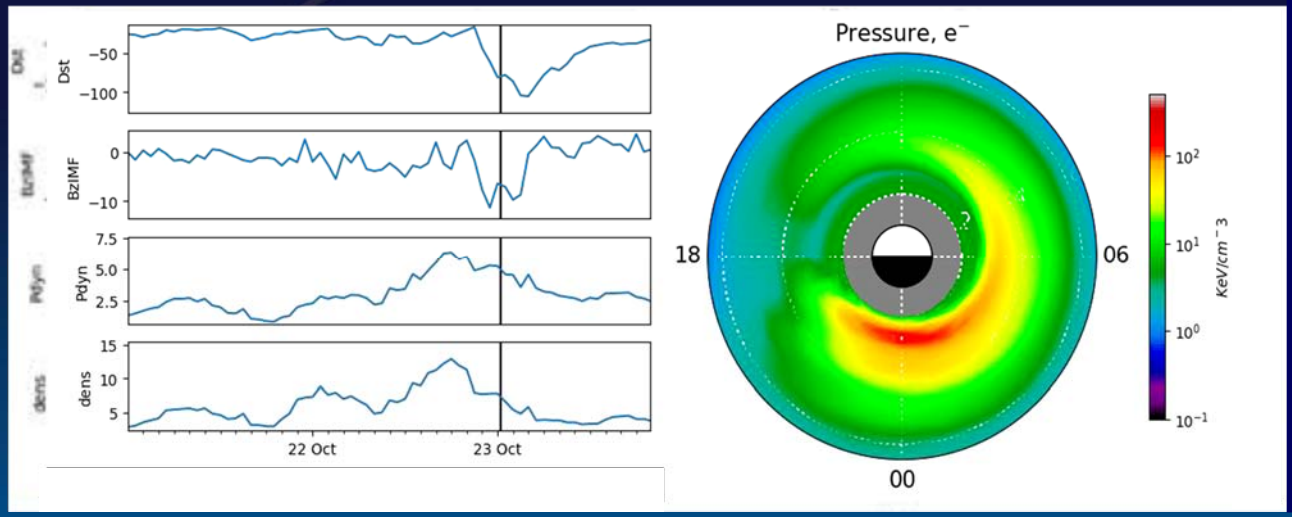
NNSA National Nuclear Security Administration

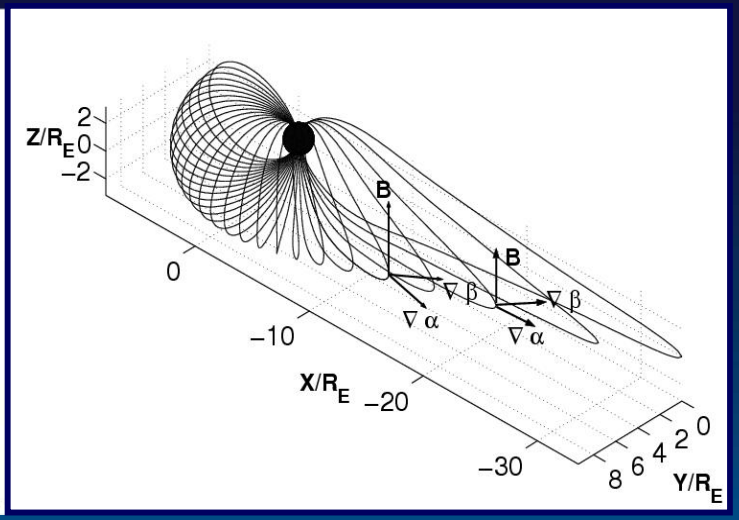
POC: Vania Jordanova, 505-667-9908, vania@lanl.gov

RAM-SCB

Ring current - Atmosphere interactions Model with Self-Consistent magnetic (B) field

Los Alamos NATIONAL LABORATORY EST. 1943





» **Ring current-atmosphere interactions model (RAM)** [Jordanova et al., 1994, 2006; 2012]

- Kinetic equation for H^+, O^+, and He^+ ions and electrons
- Including all major loss processes
- Convection and corotation E field
- Updated to general B field

» **3D equilibrium code** [Cheng, 1995; Zaharia et al., 2004; 2010]

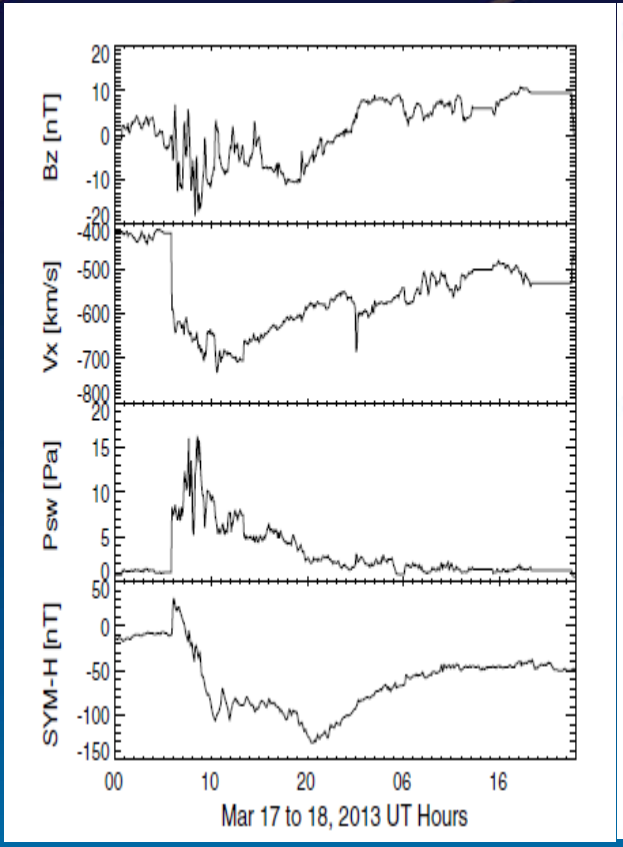
- Force-balanced equation

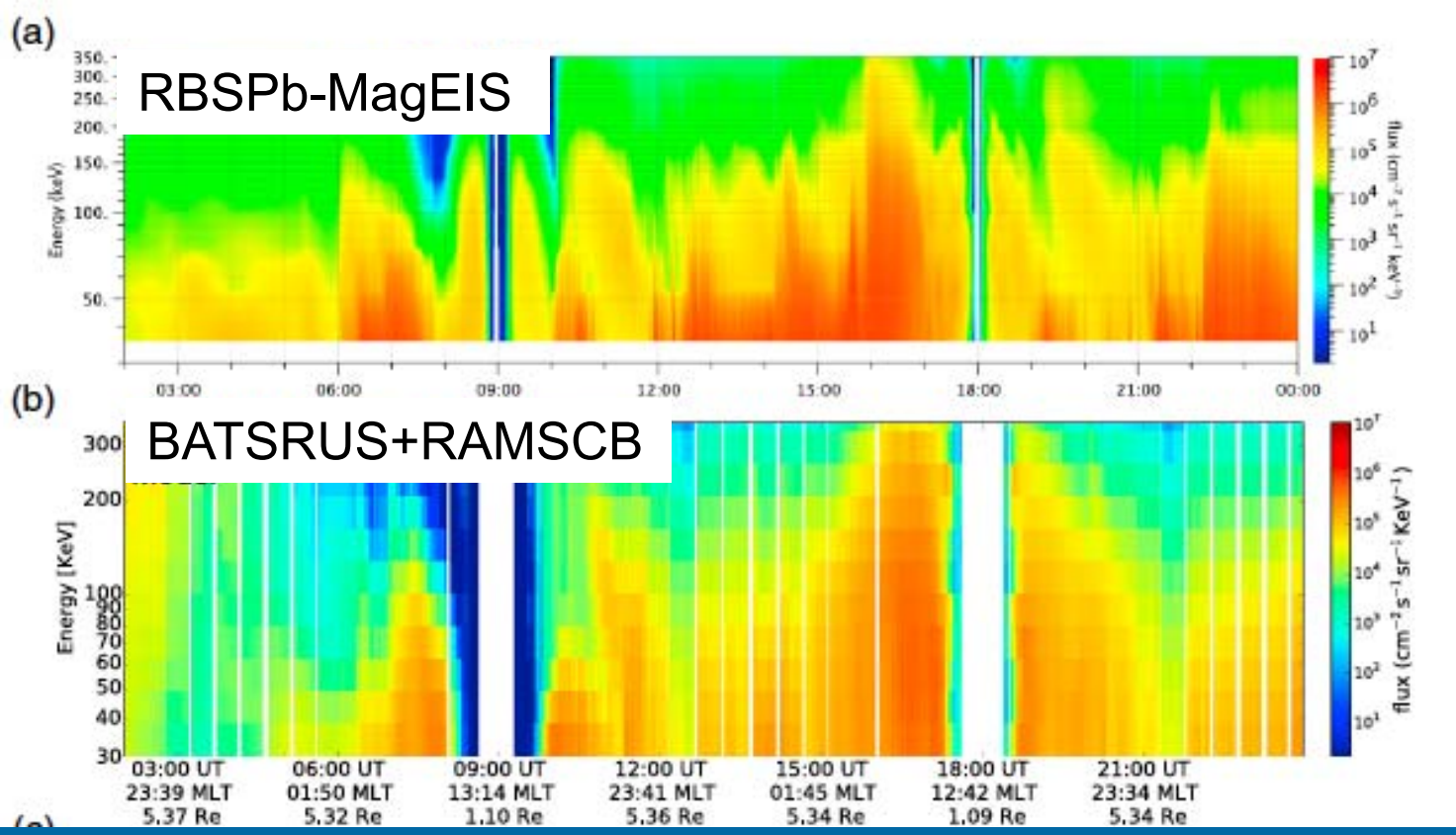
$$\mathbf{J} \times \mathbf{B} - \nabla \cdot \mathbf{P} = 0$$

- Euler potentials (flux coordinates)

NNSA National Nuclear Security Administration

SHIELDS Results: Electron fluxes





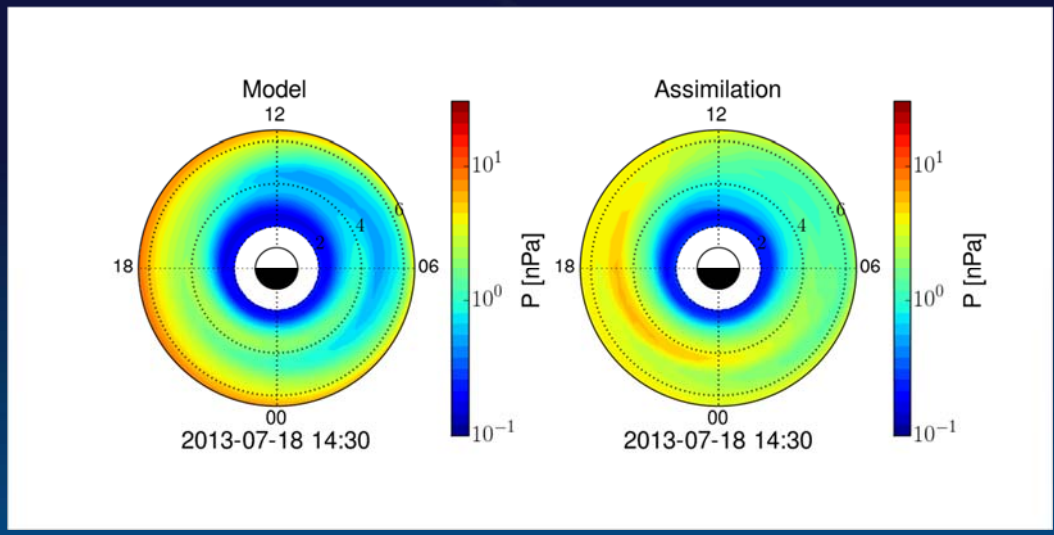
The model captures the major dynamics of the electron flux:

- ✓ **Rapid increase after the shock, energy-dispersed injections**
- ✓ **Significant enhancement of electron fluxes during the storm main phase [Yu et al., GRL, 2014]**

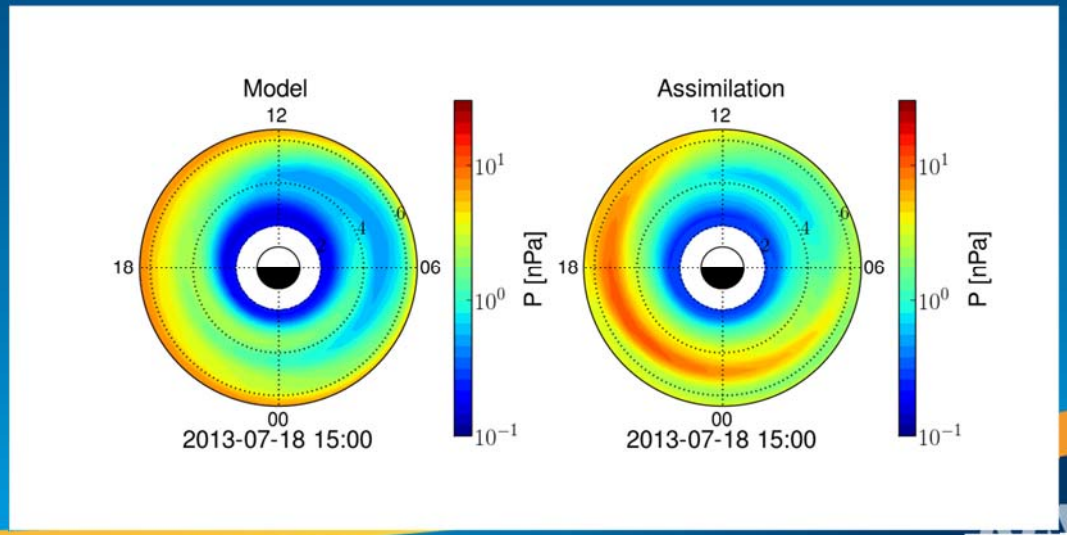
Data Assimilation

- Data assimilation fuse observations and model
- Assimilate VA Probe-B data into RAM-SCB, validate with VA Probe-A
- Use Singular Valued Decomposition (SVD) to define a new (better) basis for the state variables
- Significant enhancement is obtained compared to previous conventional method (LETKF)

Traditional LETKF method



New SVD based method

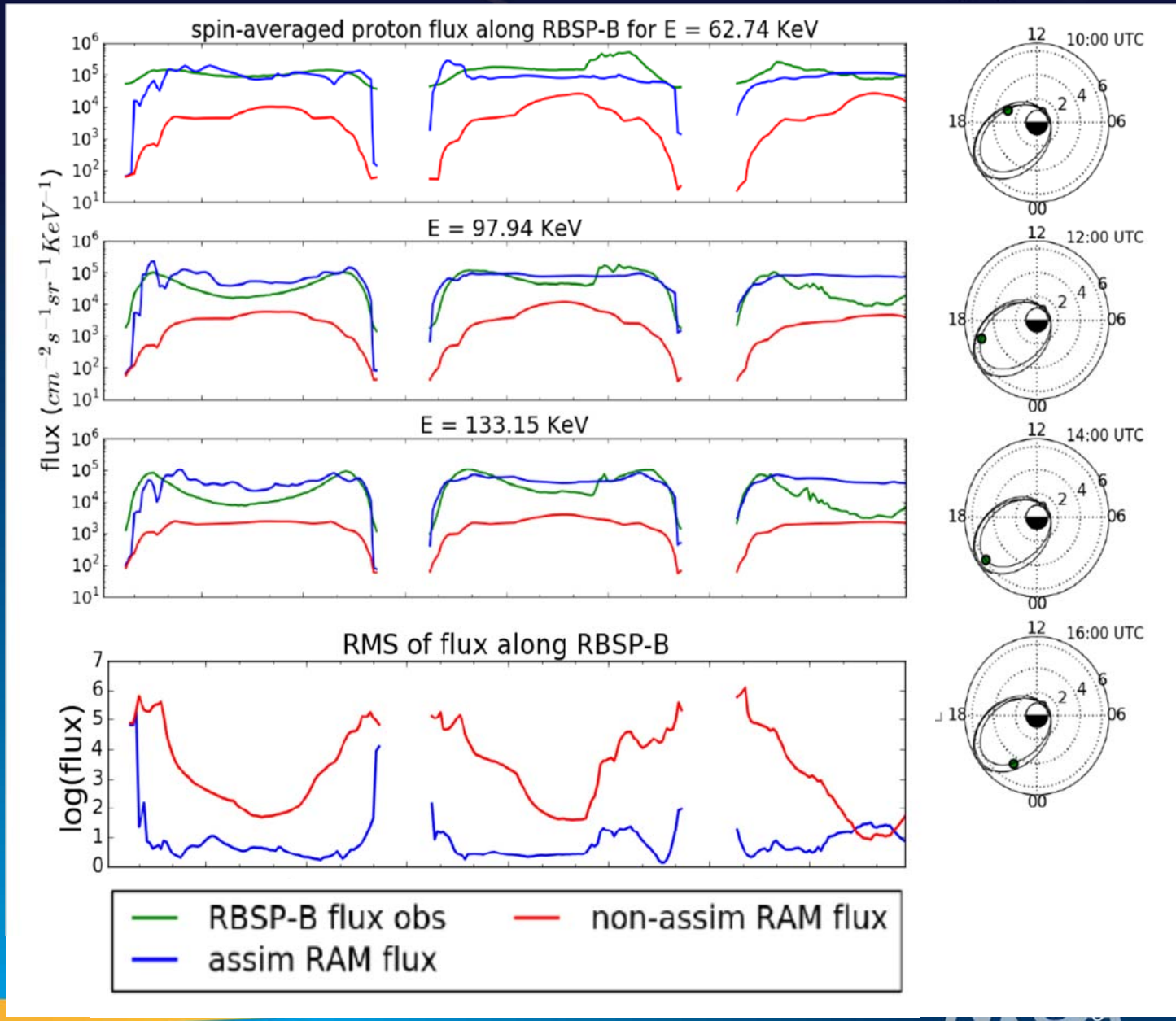


POC: Humberto Godinez, hgodinez@lanl.gov

Data Assimilation in RAM-SCB

- Assimilate VA Probe-A data into RAM-SCB, validate with VA Probe-B
- Results showed an order of magnitude improvement and significant error reduction

⇒ First data assimilation for RAM-SCB completed, paper by Godinez et al. [2016] published in the *Geophys. Res. Letters*



SHIELDS Collaborative Software Development

Migrate Codes / Developers to Distributed Version control System (DVS) ✓

- Transitioned CVS, Mercurial, etc. into a Git repository
- Work with IC-Project Filesystem & github.com/lanl/

Los Alamos NATIONAL LABORATORY EST. 1943

Institutional Computing Project Filesystem

gitlab.lanl.gov

University of Michigan Developers

LANL Users and Developers

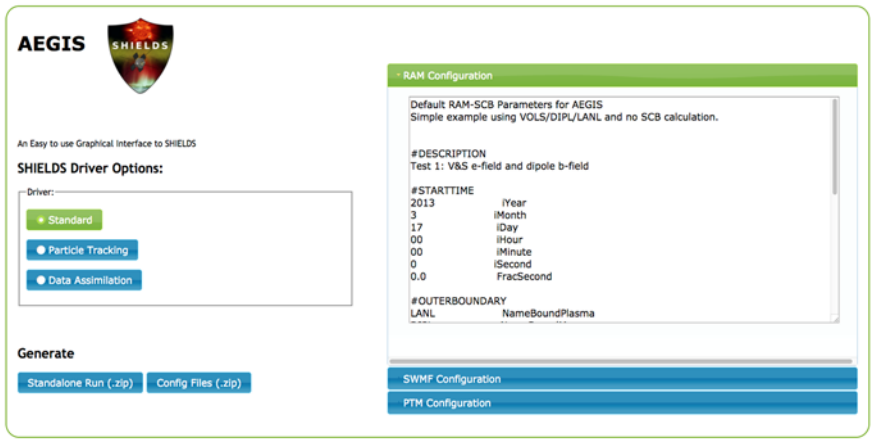
NNSA National Nuclear Security Administration

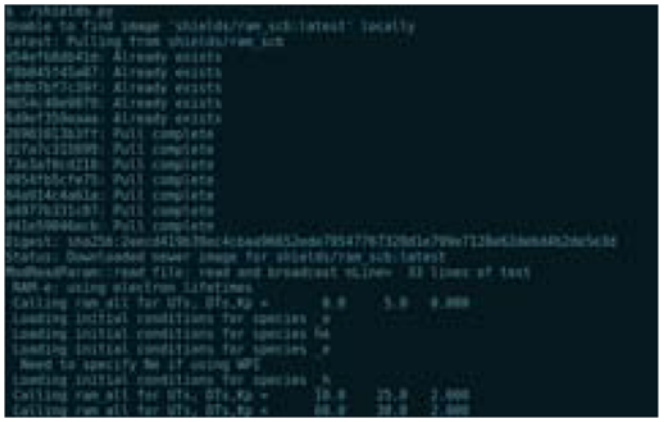
POC: Louis Vernon, vernon@lanl.gov

Compilation, Testing and Deployment of SHIELDS/RAM-SCB

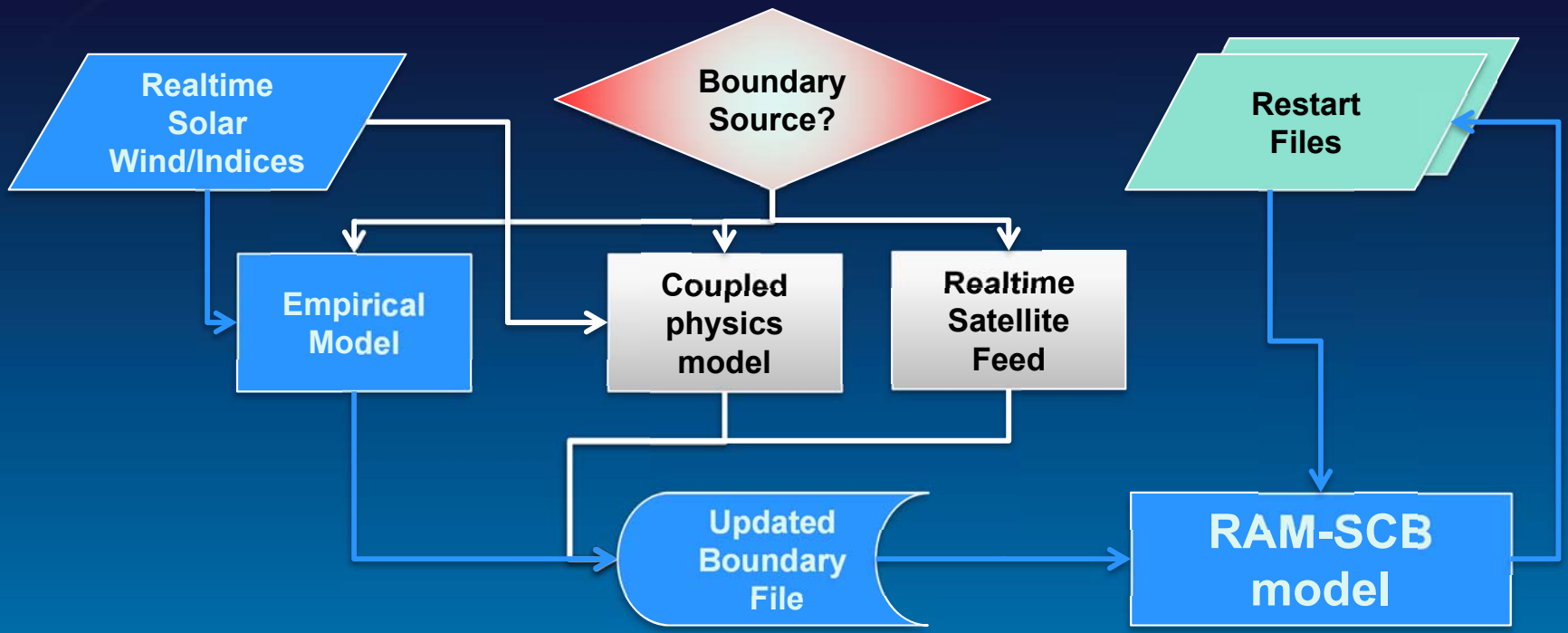
Test → Package → Distribute

Configure → Run





Real-Time SHIELDS-RC Operation
Data and Software Block Diagram



- Development of a Real-Time SHIELDS capability, a simplified RAM-SCB model driven by solar wind conditions
- Given appropriate upstream solar wind measurements, the model provides a forecast of the SCE with a ~1 hour lead time

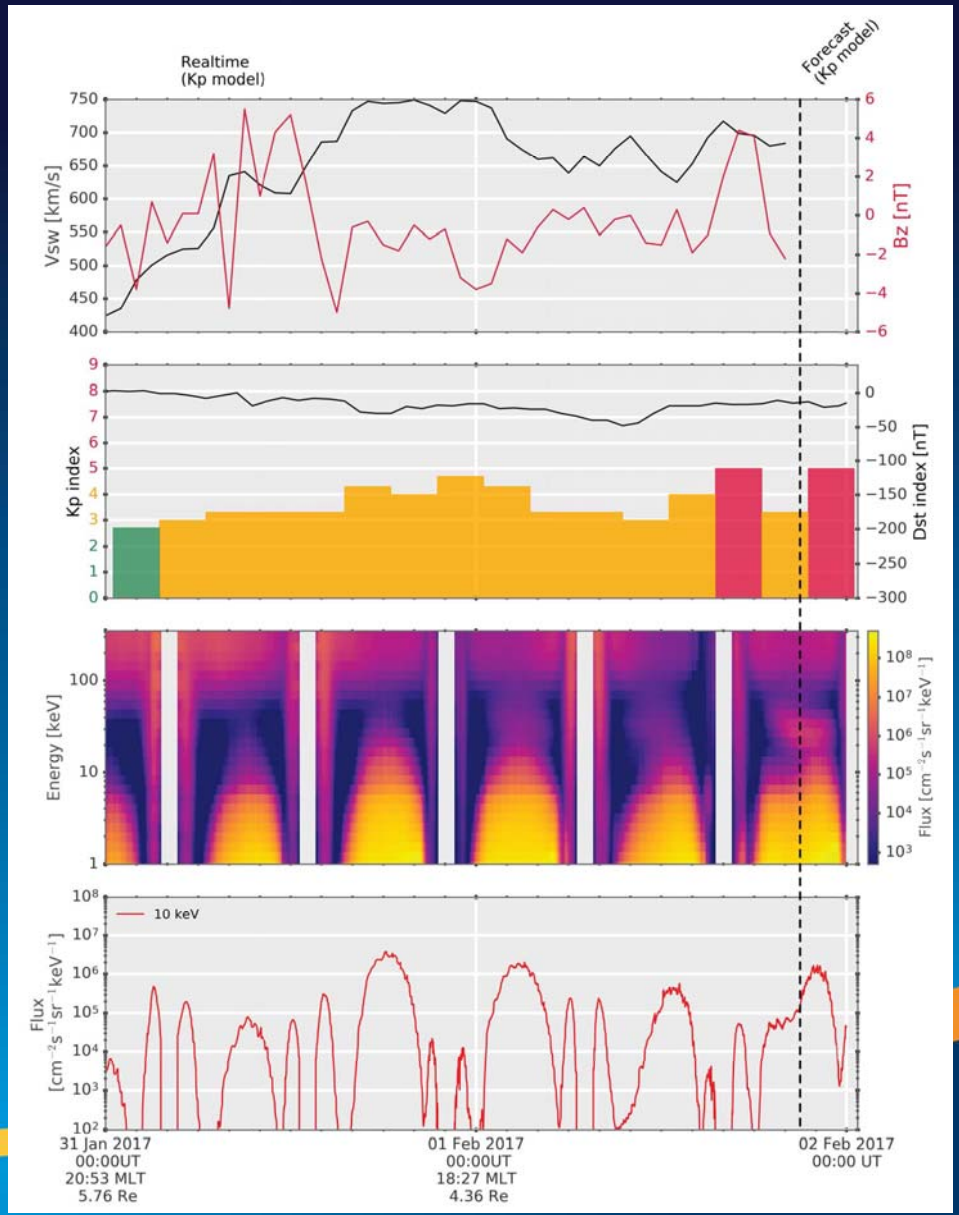
POC: Steve Morley, smorley@lanl.gov

Real-Time SHIELDS-RC Operation

Sample Model Output

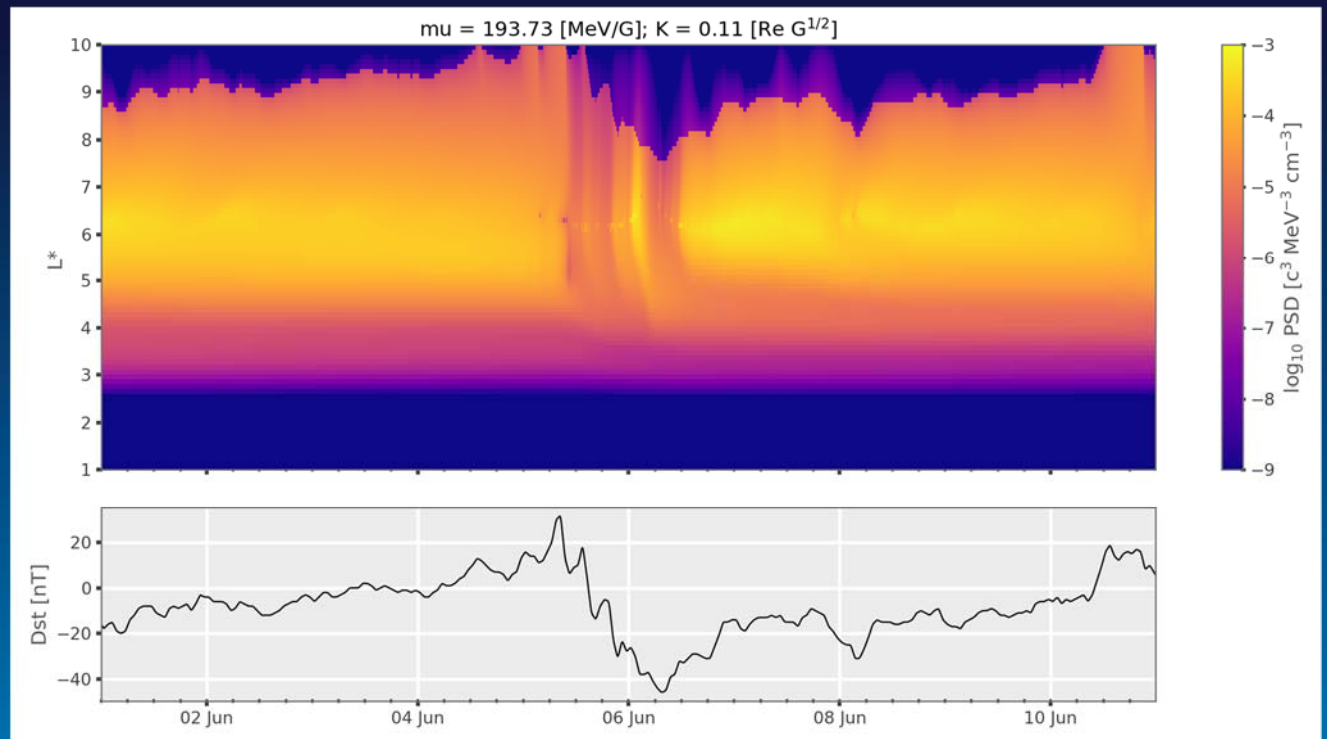
The operational SHIELDS-RC provides output along specific satellite trajectory in the inner magnetosphere, example shown for the Van Allen Probes:

- Drivers (Vsw, Bz) and Kp & Dst indices as a function of time
- Electron energy spectra from ~1 to 350 keV
- Electron flux at 10 keV as an indication of SCE hazard



Real-time DREAM: Assimilating Only GOES Data

- Generate global estimate of radiation belts with DREAM
- With only GOES, there is no radial structure other than provided by the model
- Storm onset near June 5th is clearly visible in DREAM PSD
- Reduction in PSD quickly diffuses away from GEO L-shell

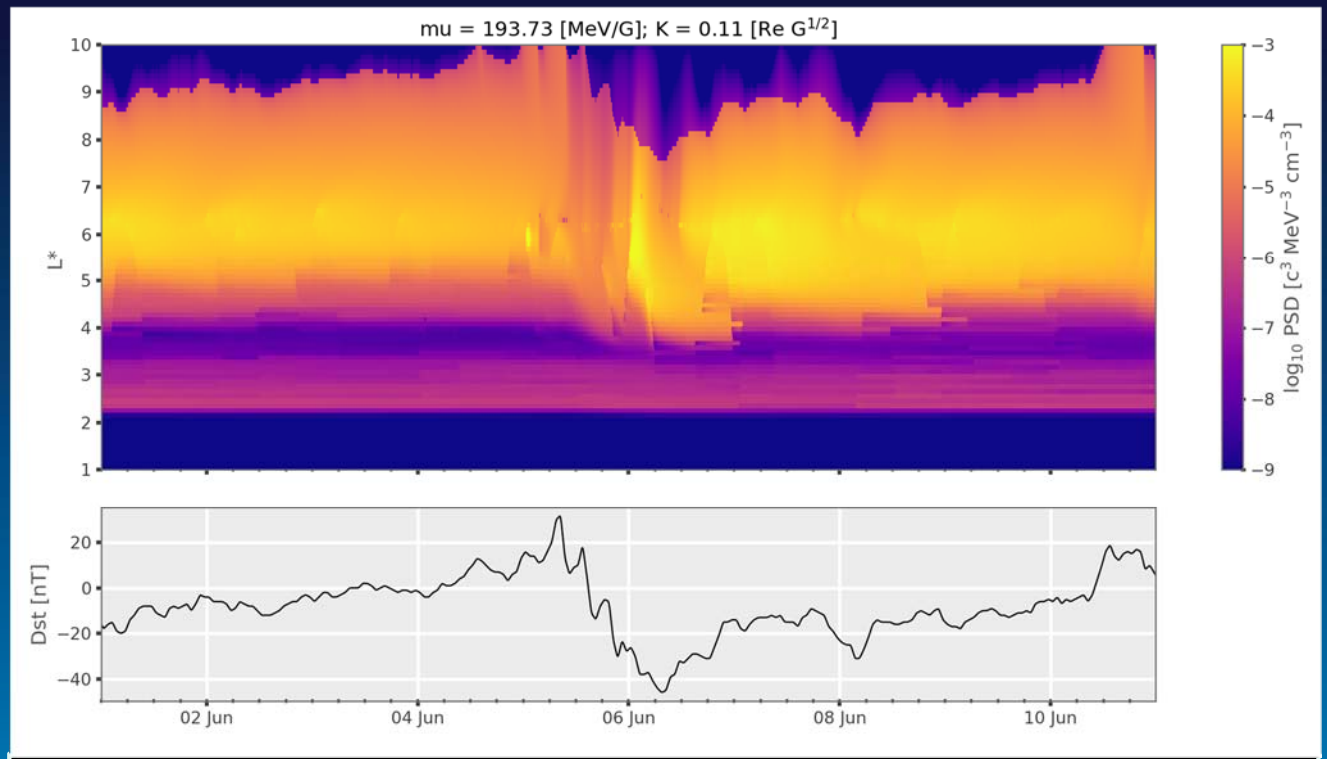


Real-time DREAM assimilated phase space density based only on GOES 13 local measurements.

POC: Andrew Walker, awalker@lanl.gov

Real-time DREAM: GOES + Beacon Data

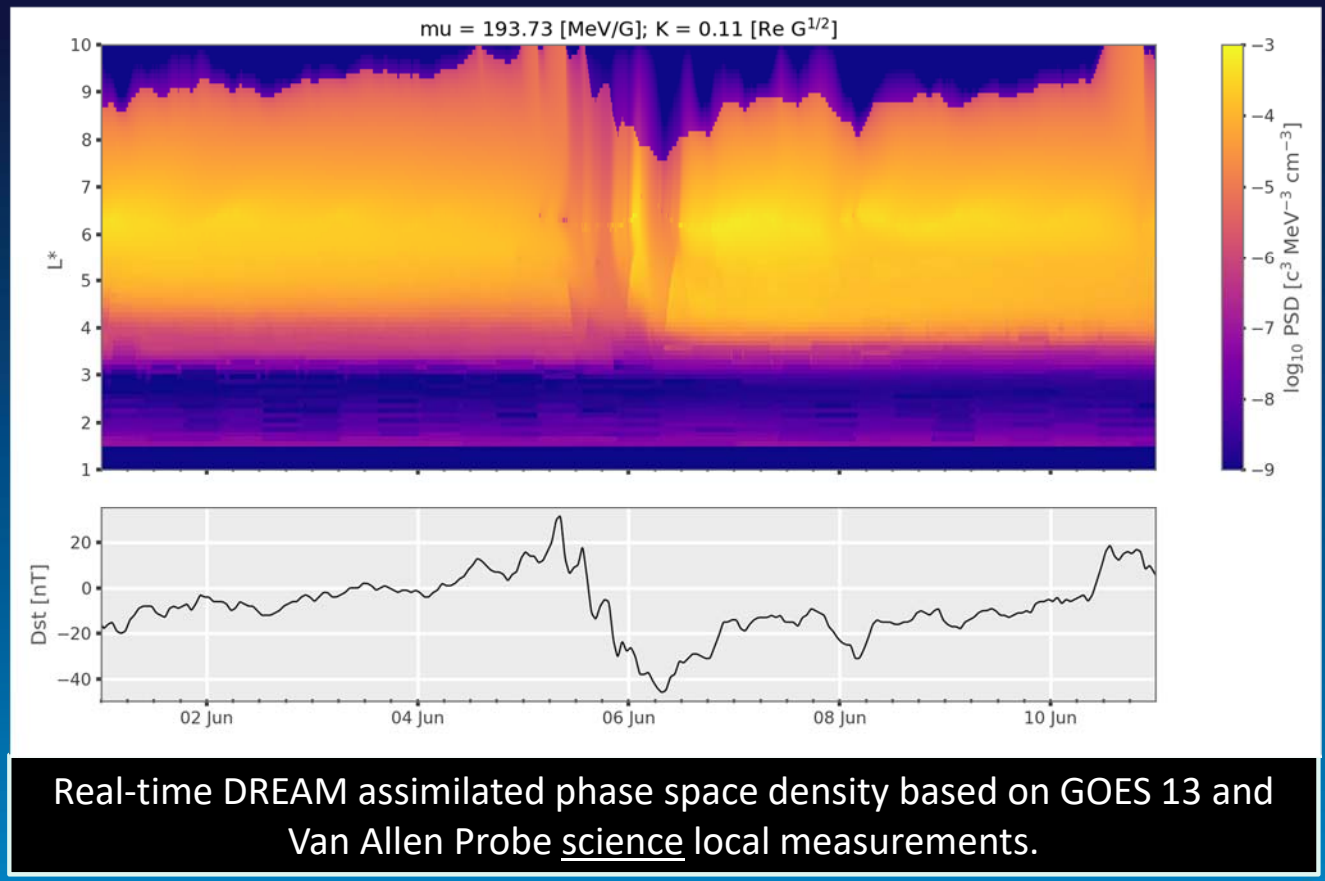
- Van Allen Probe Beacon adds additional radial structure at the cost of discontinuities in PSD
- Structure of low L-shell (3 to 4) is significantly enhanced
- Structure of L-shell from 4 to 6 is also enhanced but diffusion occurs at a faster rate in this region so discontinuities are more noticeable



Real-time DREAM assimilated phase space density based on GOES 13 and Van Allen Probe beacon local measurements.

DREAM: GOES + RBSP Science Data

- Van Allen Probe Science data provides the best assimilated PSD but is not an option for real-time processing
- Some discontinuities are still visible, but they are significantly diminished compare to the Beacon data



Real-time DREAM assimilated phase space density based on GOES 13 and Van Allen Probe science local measurements.

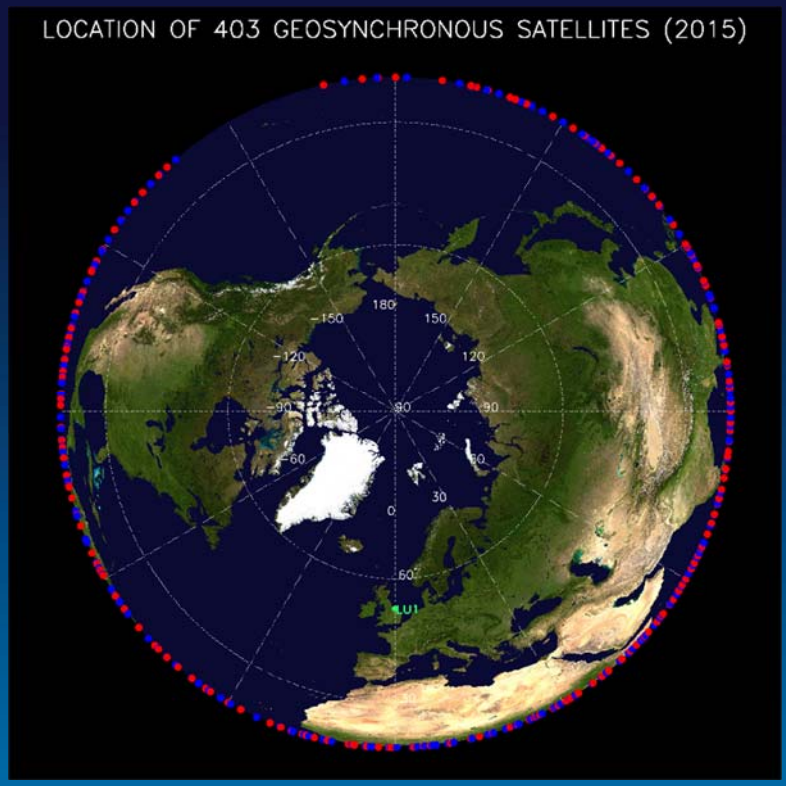
Computer, Computational, and Statistical Sciences Division CCS

SHIELDS Impact

Theoretical Division

U. Michigan

- **Space weather research is rapidly gaining public recognition as the accuracy of space weather forecasts improves**
- **We developed a space weather model for Space Situational Awareness and forensic analysis of space system failures**
- **Open source & available at: https://github.com/lanl/ram-scb**
- **SHIELDS won a R&D 100 Award in 2017; these awards honor the latest and best innovations of the past year**
- **Building strategic partnerships with other agencies (DOD, NOAA, NASA, NSF, FAA), institutions (Aerospace, universities), and commercial customers (satellite operators, etc.)**



Approximate location of over 400 military, scientific, and communications spacecraft orbiting at GEO - projected to the Earth's equator [Denton et al. *Space Weather*, 2016].

- **Website with lists of presentations and publications: http://www.lanl.gov/projects/shields/**

NNSA National Nuclear Security Administration